43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
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THE 43TH TURBO MACHINERY SYMPOSIUM CASE STUDY

CGC LARGE STEAM TURBINE VIBRATION RESONANCE OF PEDESTAL AND LINKAGE SYSTEM RCA, DETAIL VIBRATION INVESTIGATION/MEASUREMENT AT SITE AND COUNTERMEASURES

TEXAS A&M UNIVERSITY

TEES
TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

The 43th Turbo machinery Symposium Case Study

CGC Large Steam Turbine
Vibration Resonance of Pedestal and Linkage System
RCA, Detail Vibration Investigation/Measurement at Site and Countermeasures

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Kyoichi Ikeno

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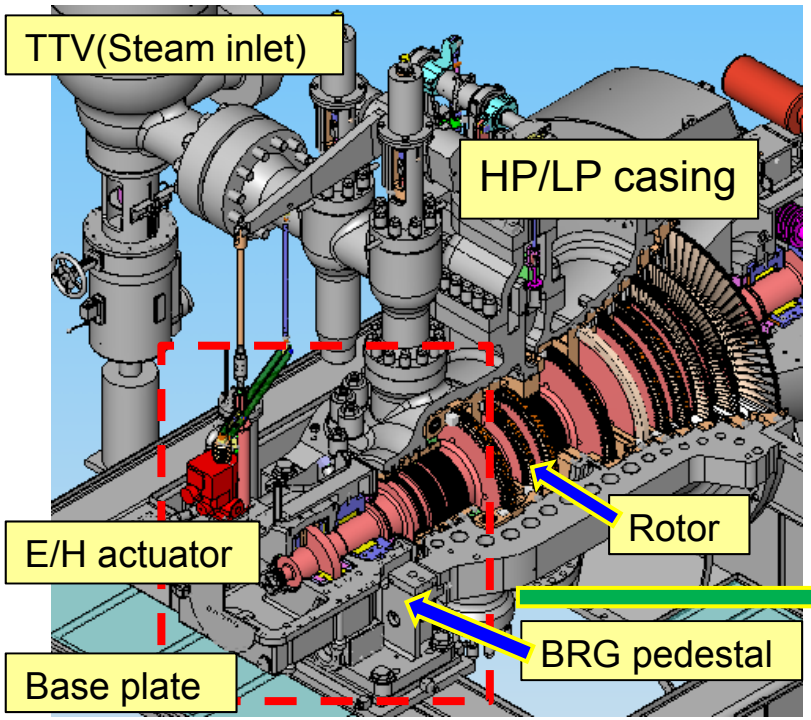
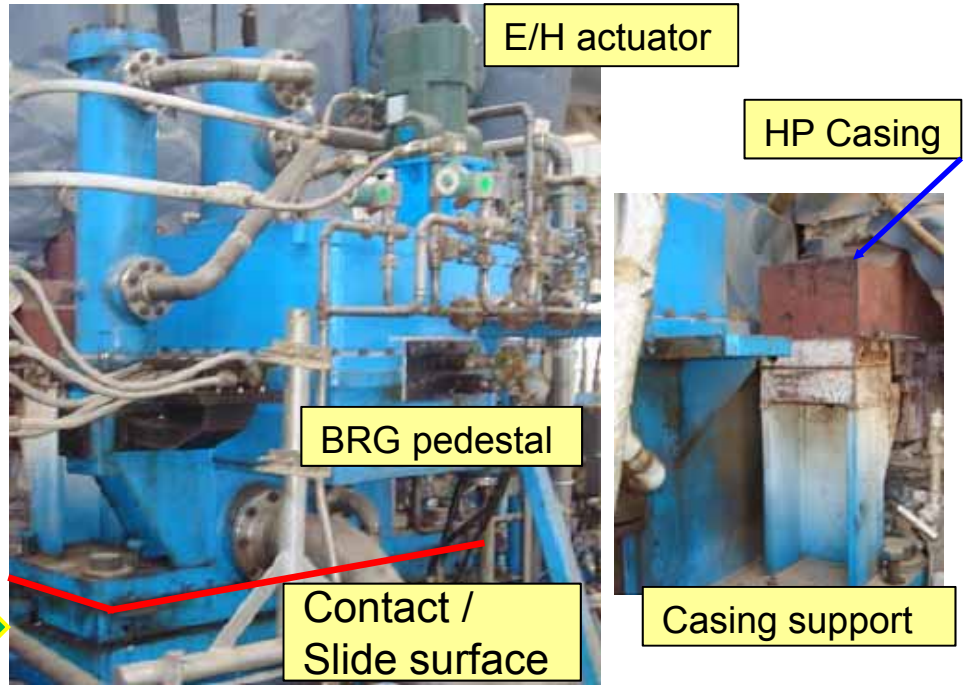
1. Specification of Steam turbine with Gov, side pedestal



Section drawing of 9EH model turbine



Gov, side brg, pedestal with cover assembly

Turbine specification ;

Max, power ; 60MW
Speed ; 2830 rpm – 3845 rpm
Plant start ; from 2002

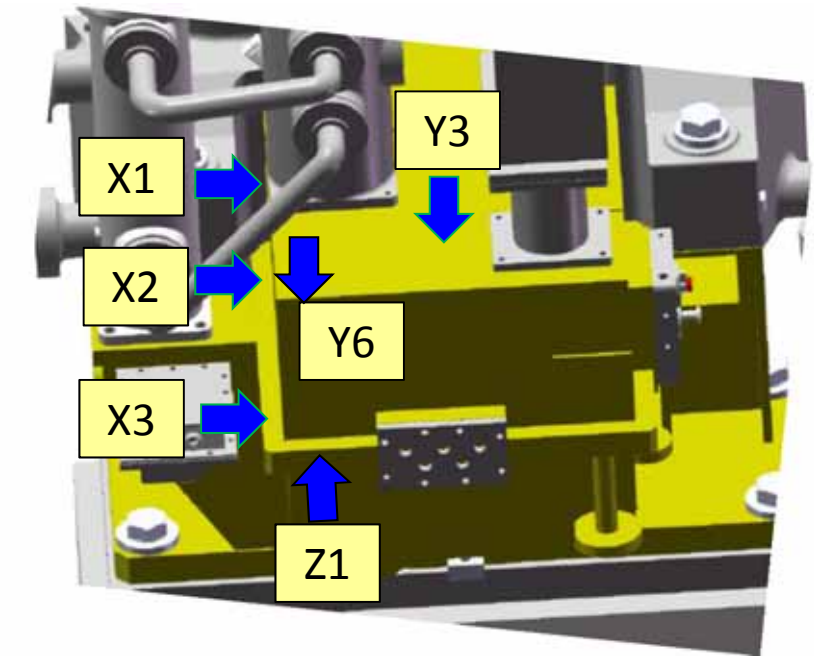
Major specification of bearing pedestal with cover assembly;

1) Fabricated welding structure
2) Separated casing support
3) Material is Carbon steel (Eq, ASTM A36)

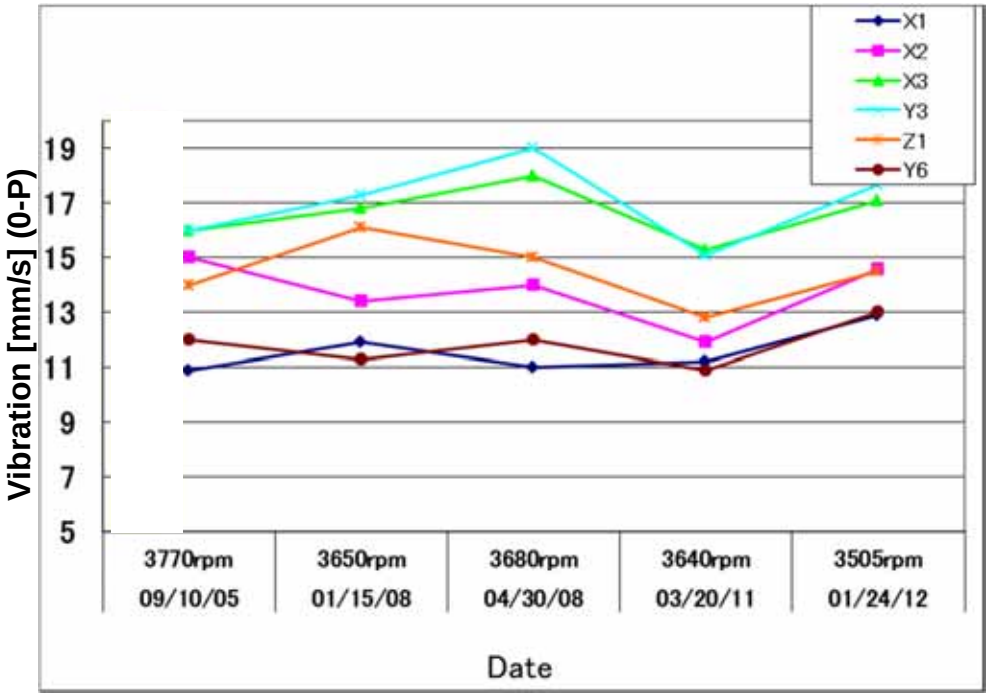
2.1 Background *Historical of bearing pedestal vibration phenomenon at site*

Historical events at field ;

- **Turbine start up in 2002**
- **Gov, side pedestal Vibration increase from around 2005**
- **Vibration up to 20 mm/s in 2012 by turbine load/speed up**
- **Vibration causes linkage wear and required control limit**

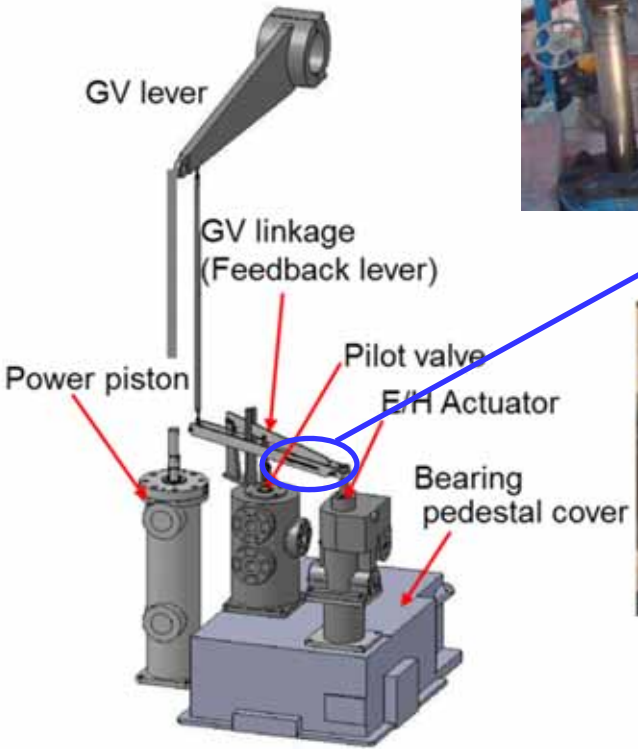


Site measurement points
(View from Gov, side)



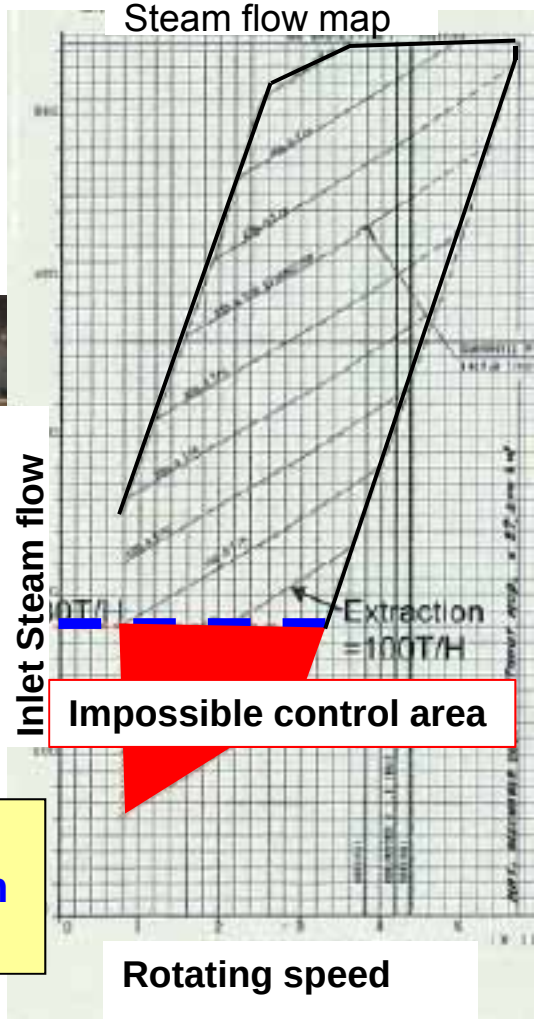
Pedestal vibration record from 2005 to 2012

2.2 Background *Historical of bearing pedestal vibration phenomenon at site*



GV linkage damage condition

Feedback lever



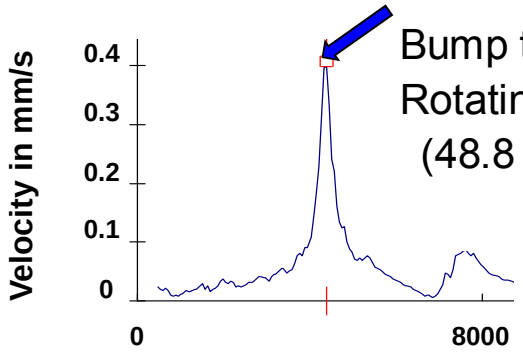
Operation condition ;
It was shifted actual inlet steam flow against E/H actuator signal.

2.3 Background *Historical of bearing pedestal vibration phenomenon at site*

Site measurement record ;

One sensor is fixed and the sensors(for H, V, A direction) are removed to the points together.

Each vibration phase is evaluated by transfer function from the fixed point to each points.

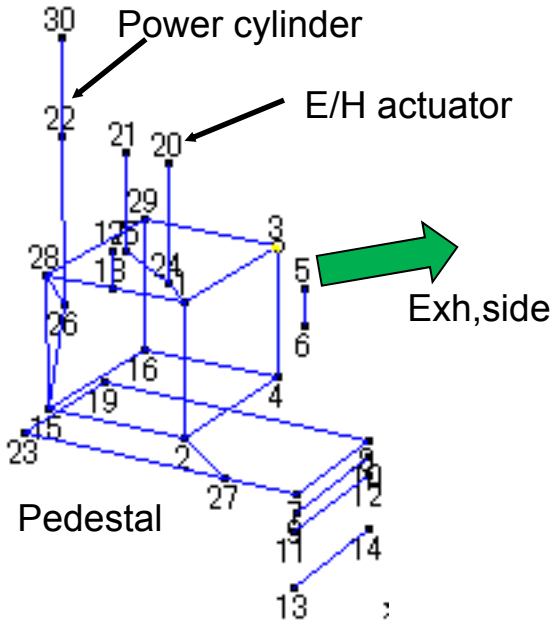


Bump test result ; 73 Hz(Natural frequency)

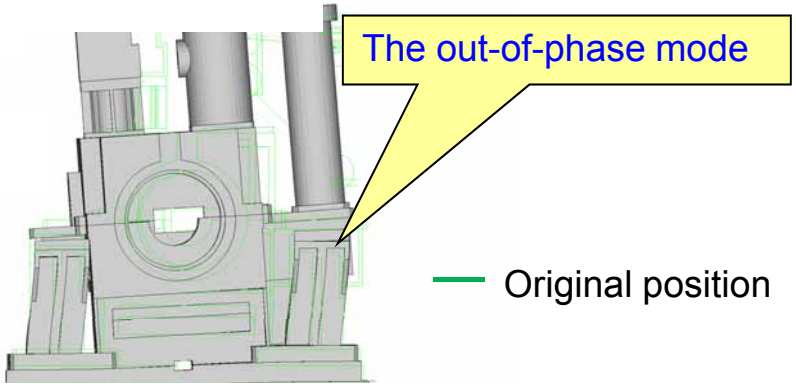
Rotating speed

(48.8 to 64Hz(2830 to 3845rpm))

Bump test result of pedestal



Site measurement points diagram



Measured vibration mode at 3555 rpm (59Hz)

The main characteristic of the vibration mode is an out-of –phase (counter-motion) mode between main pedestal and casing support

Measured vibration mode under operation
(View from Exh, side)

3. Root Cause Analysis for Bearing Pedestal Vibration

RCFA ;

Root cause failure analysis found on 3 main items as below;

1, Excessive external force

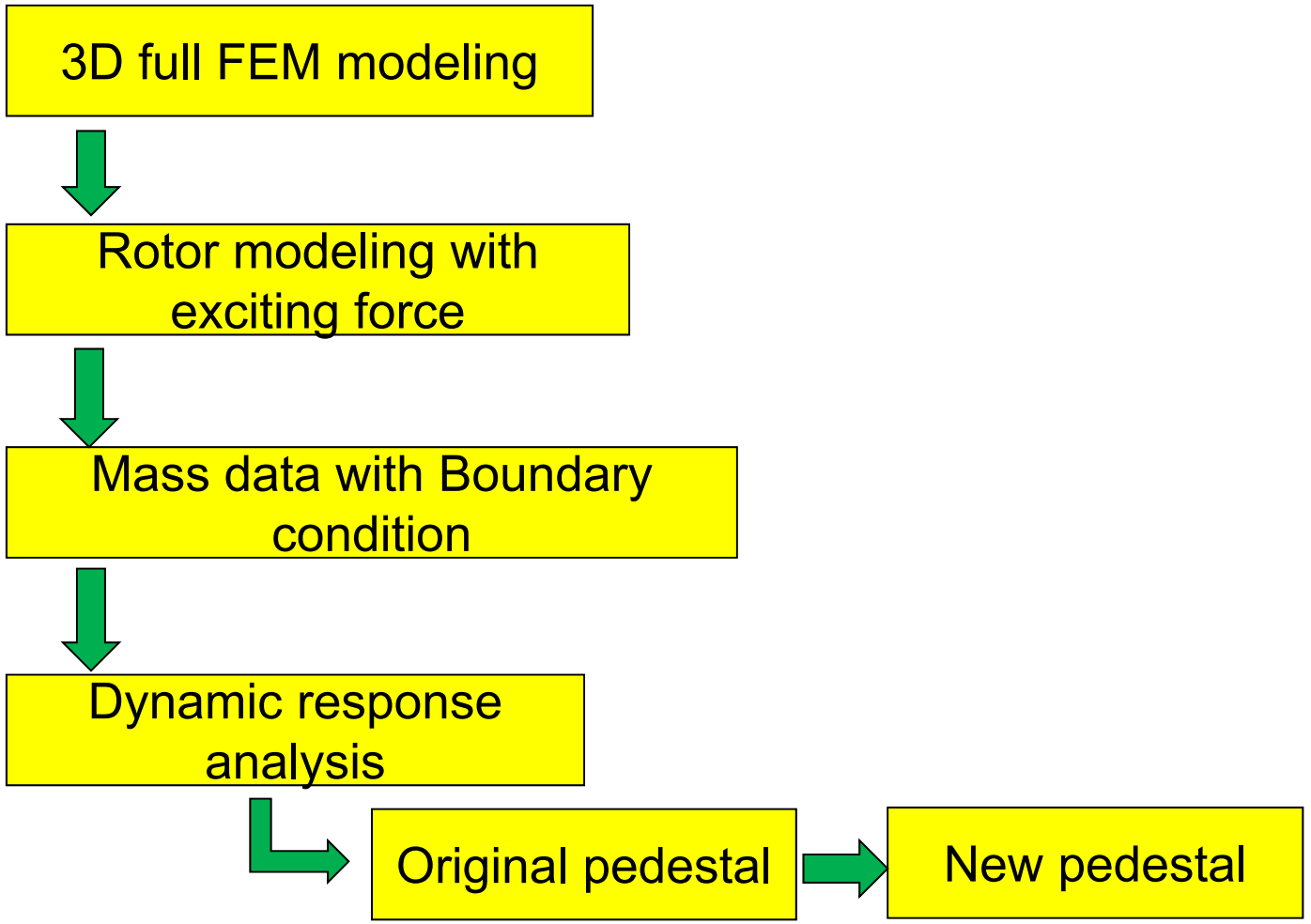
2, Increase of modal mass on bearing pedestal

3, Decrease of dynamic stiffness

- **Foundation degradation**
- **Bearing pedestal stiffness**
- **Natural frequency excitation**

4.1 Response analysis of 3D Full modeling

In order to clarify the vibration mechanism, it performed vibration 3D response analysis(cod-Nastran) with current bearing pedestal incorporate measurement result of site condition.

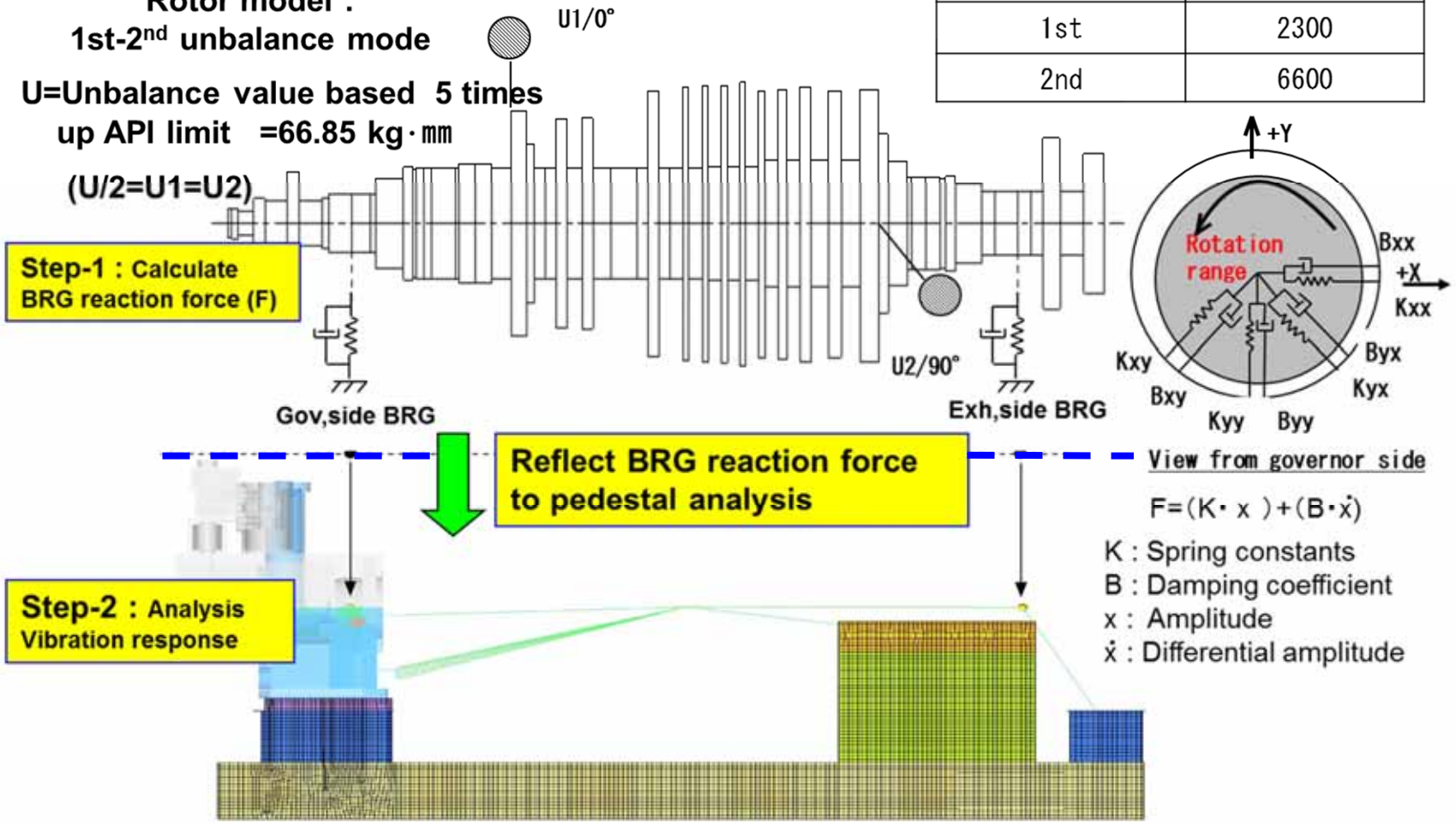


4.2 Response analysis of 3D Full modeling

Rotor modeling with excitation force calculation

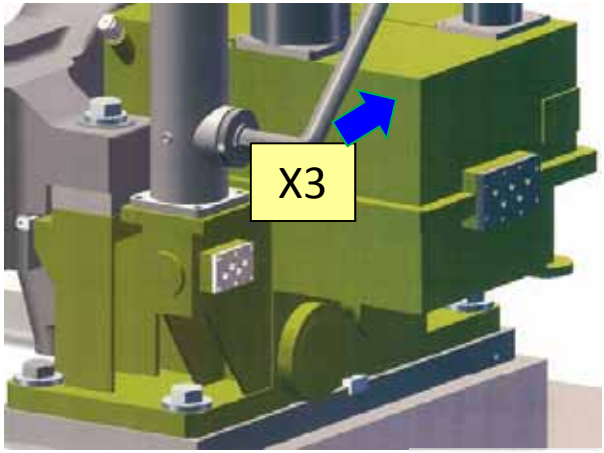
Calculation of BRG reaction force by rotor unbalance response (Code=ROT-CAE)

Critical speed	Speed (rpm)
1st	2300
2nd	6600

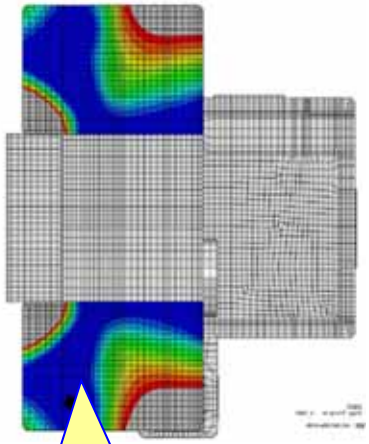


5.1 Analysis result of original pedestal in hot condition

Final analysis results of fabricated pedestal type

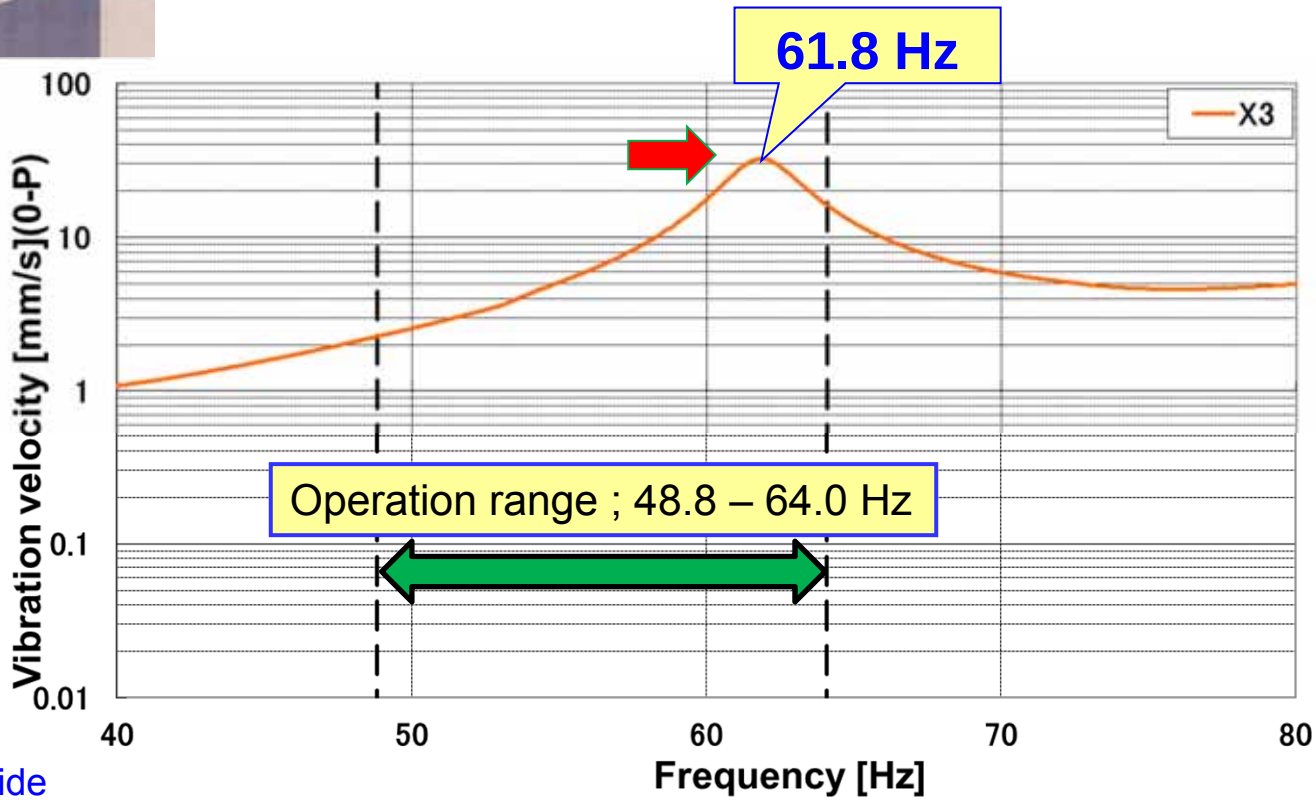


Result;
- Natural frequency 61.8Hz is in to the turbine operating speed range.
- Vibration level in analysis is 10 to 30mm/s 0-P around normal to max speed.



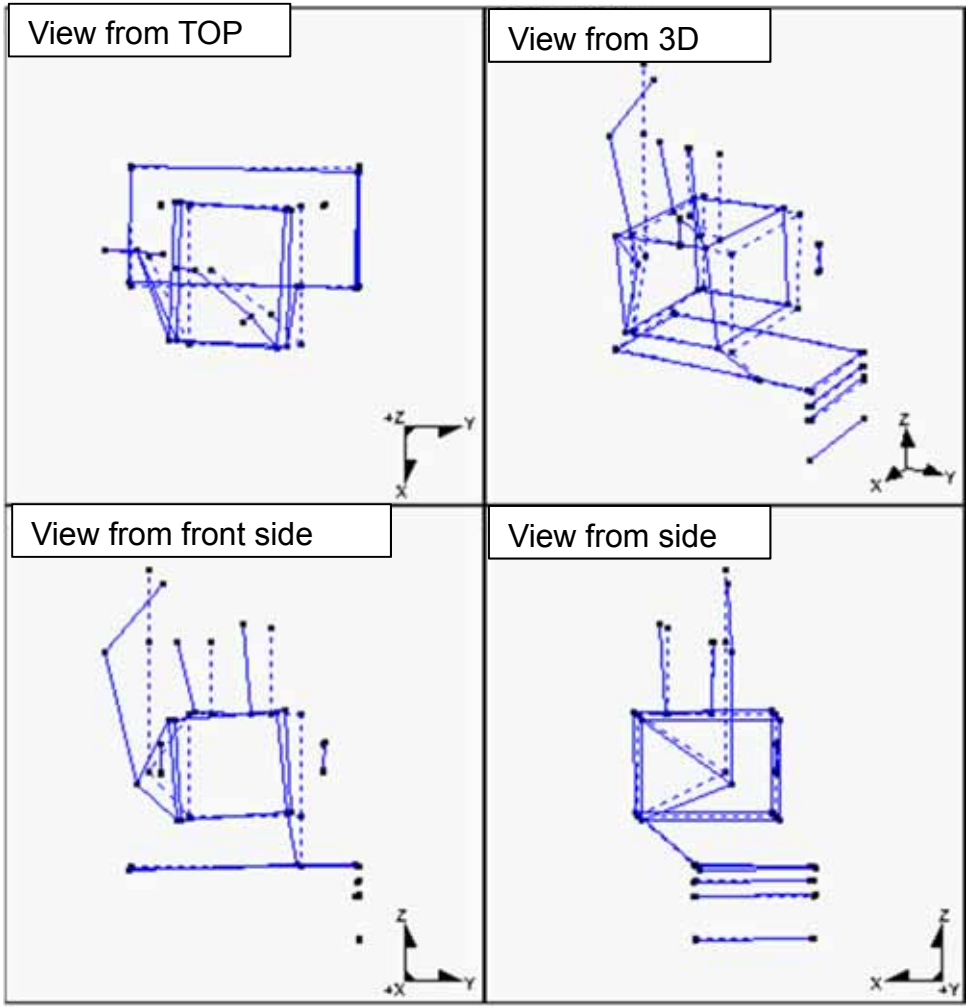
Full contact blue colored only

View from pedestal lower side



5.2 Analysis result of original pedestal in hot condition

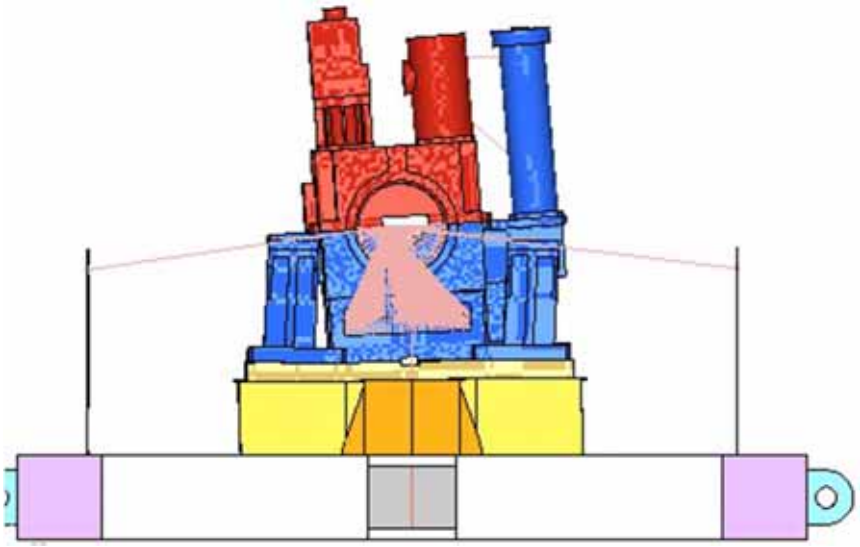
Comparison between Measurement data and
Analysis result by animation mode.



Measured vibration mode at site

Result;

- 3D response analysis method is almost suitable for site operating condition.
- The out-of-phase mode between main pedestal and upper casing support under.



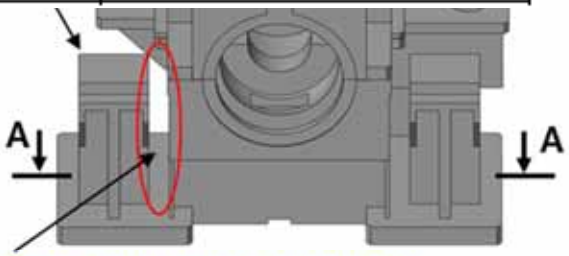
Analysis vibration mode result
(View from Exh, side)

6. Comparison of original and improved pedestals

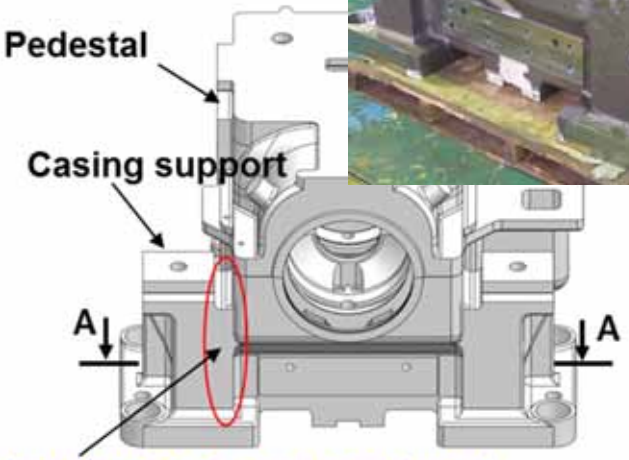
Requirement for new pedestal design;
1) Applicable full contact condition of pedestal surface.
2) Rigidly connection between pedestal body and casing support without freestanding.

Existing pedestal & cover	New pedestal & cover
Carbon steel SS400 (Eq. ASTM A36)	Cast steel SC450 (Eq. ASTM27-93 Gr65)
Pedestal : 1590 kg	Pedestal : 1880 kg

Overview

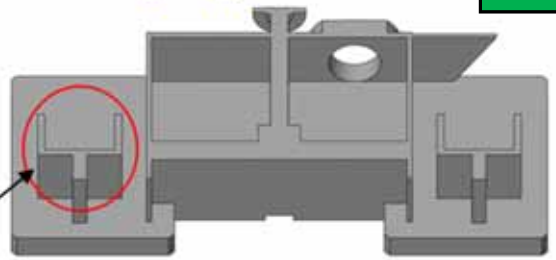


Free standing of pedestal and casing support

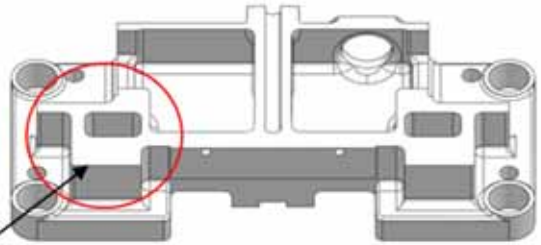


Integration between pedestal and casing support

Cross section A-A



Optimized thickness support



Robust support

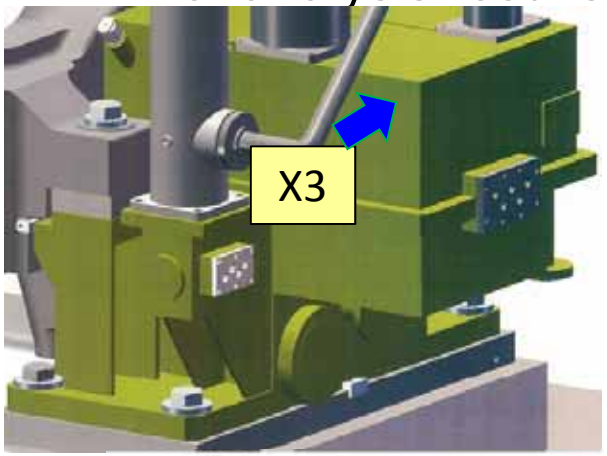
Old fabricated type

New casting type

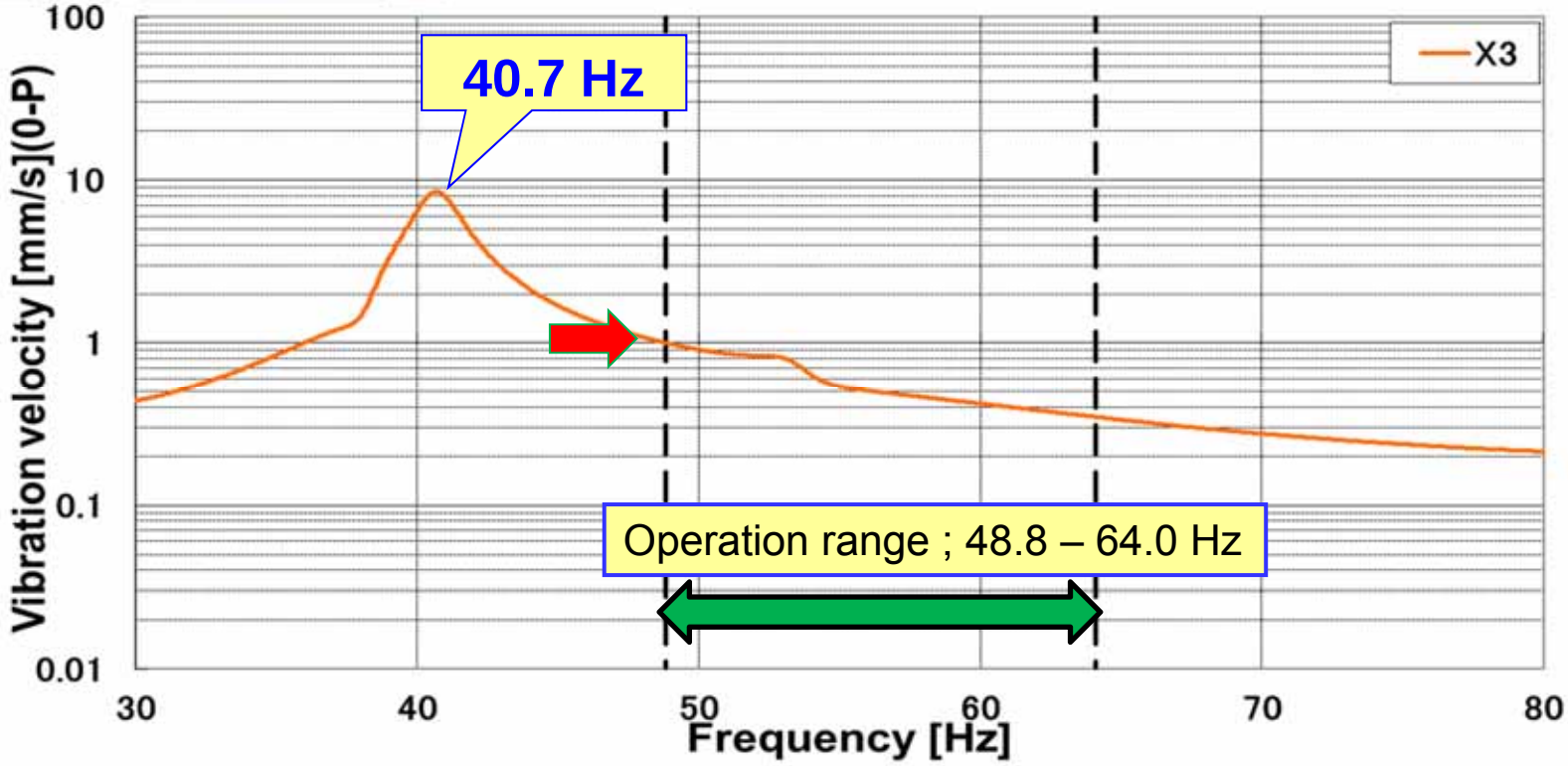
Casting pedestal type has more high stiffness than current fabricated type

7.1 3D analysis result of improved pedestal in hot condition

Final analysis results of Casting pedestal type

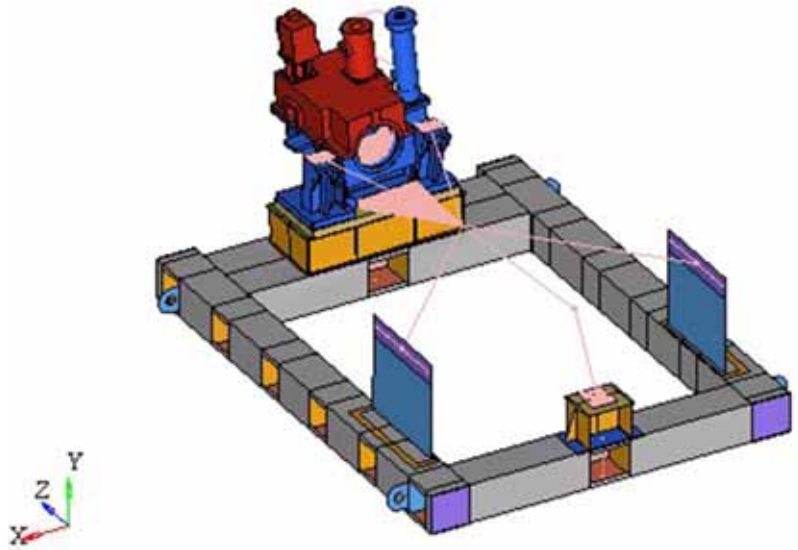


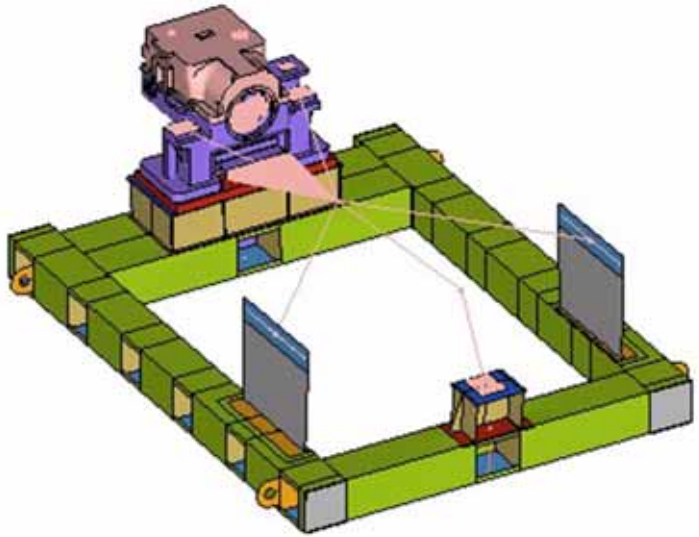
Result;
a) Natural frequency 40.7Hz to be satisfied with API standard (less than 41Hz), and out of operation range.
b) Vibration level in operation to be much lower at 0.3 to 1 mm/s 0-P even by 5-time of API limit



7.2 3D analysis result of improved pedestal in hot condition

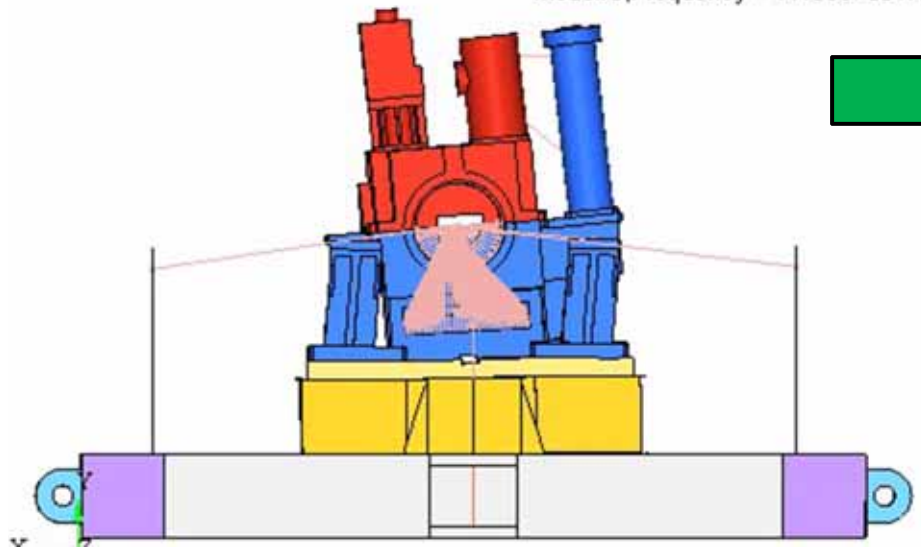
Following shows vibration mode of animation for improved pedestal and original.

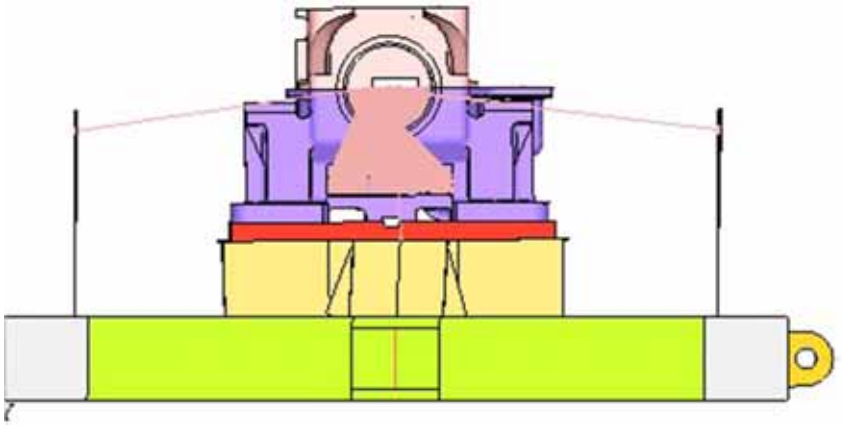




Mode#5,Frequency= 7.130e+001Hz

Mode#3,Frequency= 4.541e+001Hz



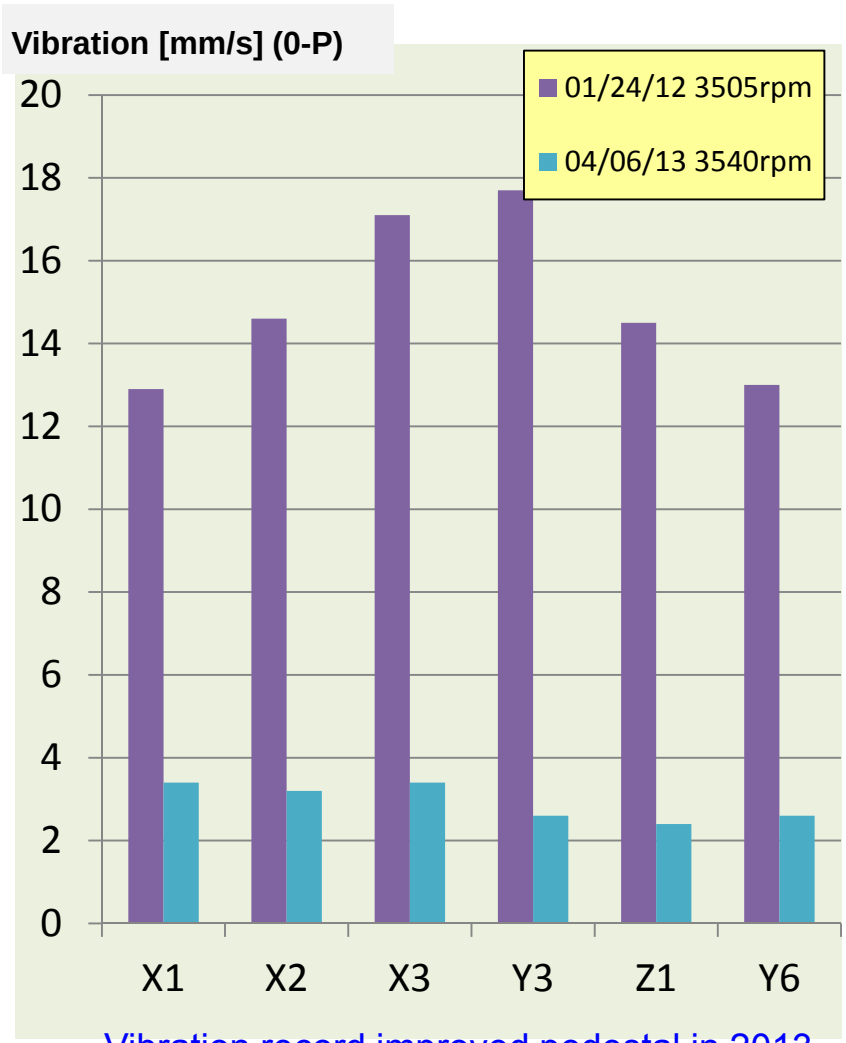


Original pedestal analysis in hot condition

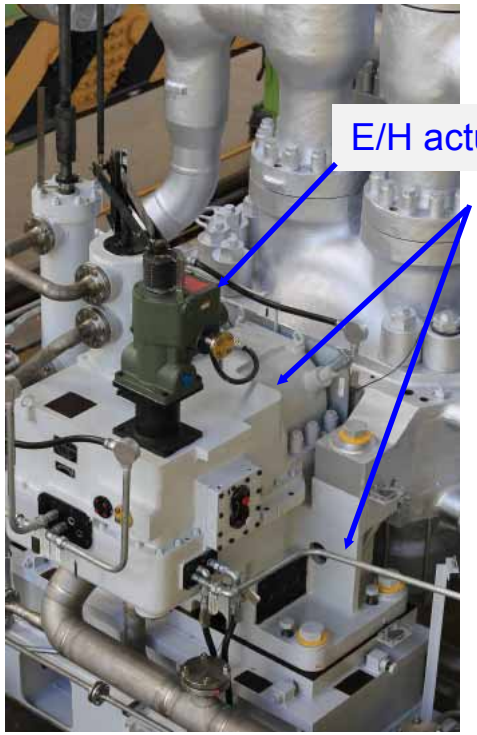
Improved pedestal analysis in hot condition

8. Site verification result for permanent solution

Result for applying of new improved pedestal



Vibration record improved pedestal in 2013



Outline of application to similar 9EH turbine

Result ;
Vibration level in rotating speed to be much reduced to less than 3.0 mm /sec (0-P) , which means reduction of 80% compare with the existing pedestal vibration level.

9. Conclusion

1) Summary of analysis result

Pedestal	Natural frequency	Vibration level in operation	Note
Casting type (Improved design)	40.7Hz	Less than 1mm/s 0-P (H-direction)	17% separation margin against 48.8Hz (Min. speed) satisfied with API standard of more than 16%
Fabricated type (Original design)	61.8Hz (Hot condition)	Less than 30mm/s 0-P (H-direction)	Almost same as site bump test (73Hz) with cold condition 69.2Hz.

2) 3D response analysis was carried out using field measurement data.

- Analysis was confirmed root cause of vibration.
- Model used to design new bearing pedestal and confirm vibration include separation margin.
- Bearing pedestal retrofit to similar machines.
- Field record verified improved vibration response.

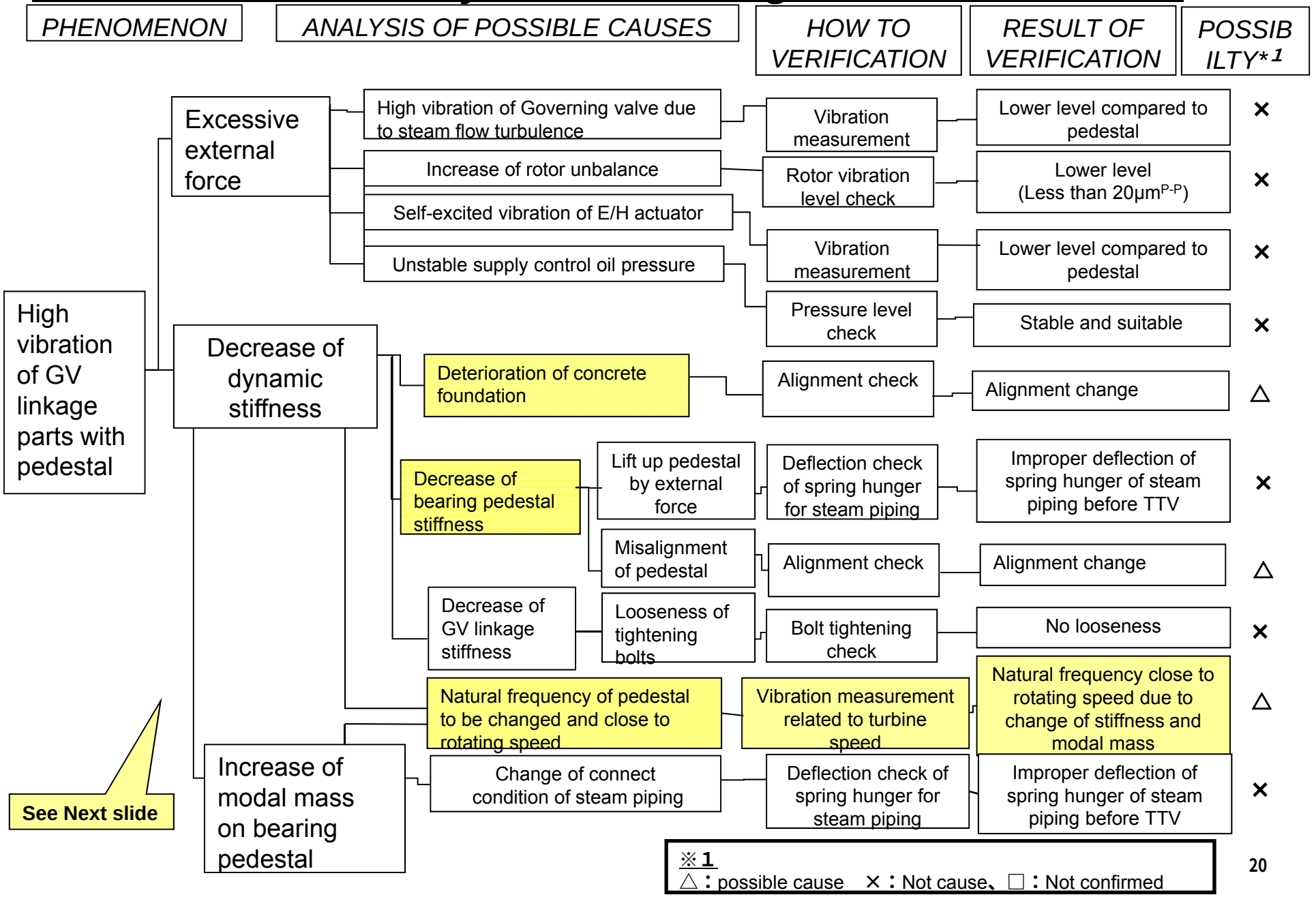
Thank you for your attention

Author's biographies ; Makoto Katagake

Makoto Katagake is the Senior Mechanical Engineer of the Turbine Design Section, Mitsubishi Heavy Industries Compressor Corporation, in Hiroshima, Japan.
It has experience detail design of mechanical components with R&D for mechanical drive turbines for 20 years.

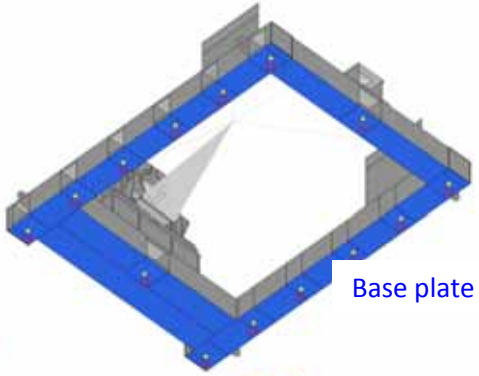
Back up materials

3.1 Root Cause Analysis for Bearing Pedestal Vibration



4.3 Response analysis of 3D Full modeling

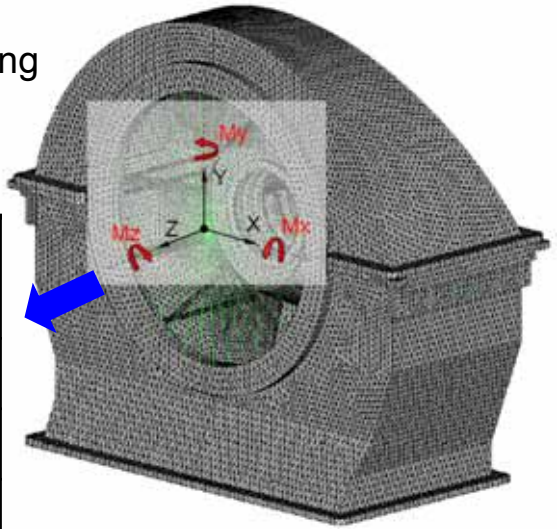
b) Turbine structure modeling with loading data



Base plate fix condition

△ :Fix point

LP casing



	Stiffness (kgf･mm/rad)
Mx	2.1×10^{10}
My	2.8×10^{10}
Mz	5.6×10^{10}

Casing support
11250×2 kgf

Pedestal

Gov. side rotor
4000 kgf

(Without wedge plate)

Casing

HP casing side
=Infinite rigidity
LP casing side
=Finite stiffness

Exh. side rotor
4000 kgf

Exh. side flexible plate
13167×2 kgf

Exh. side pedestal
2767 kgf

Base plate

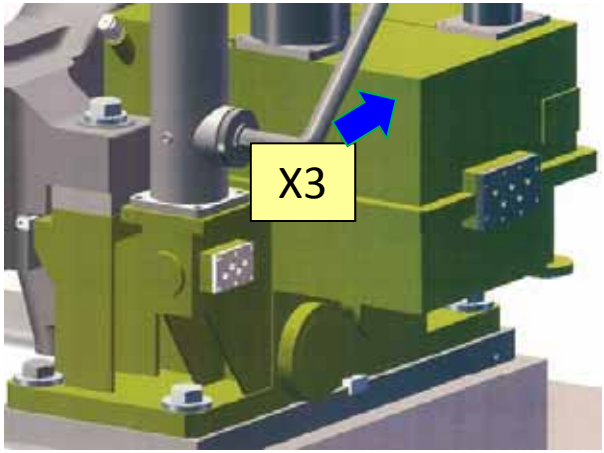
Full contact condition

Excitation force:
BRG reaction force based on 5 times API limit unbalance

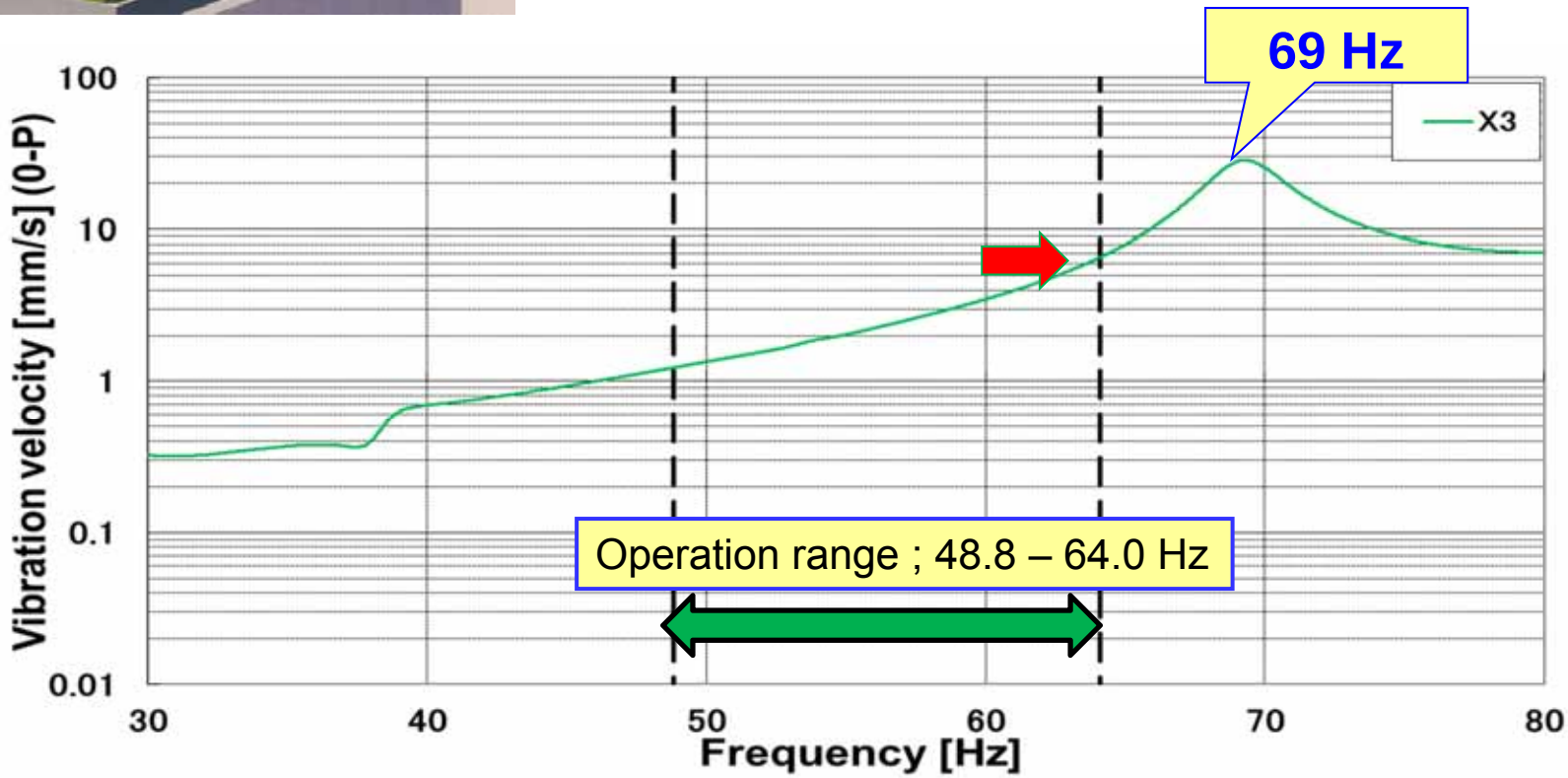
Vibration analysis 3D-model

5.3 Analysis result of original pedestal in cold condition

Final analysis results of fabricated pedestal type



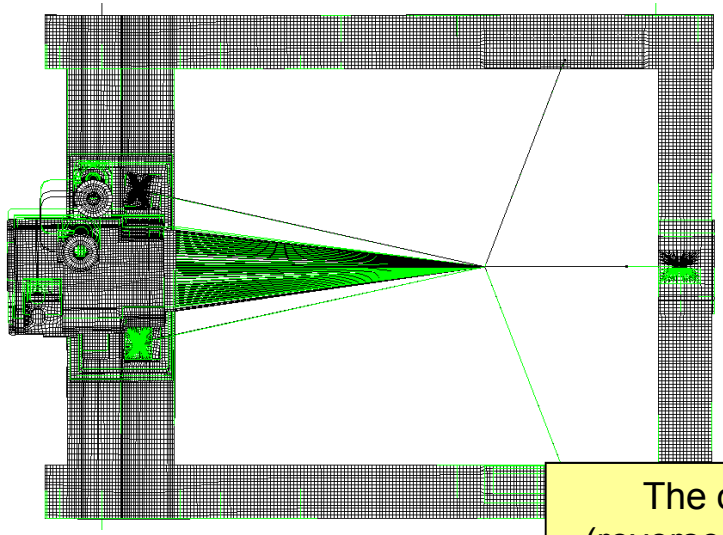
Result;
- Almost matches analyzed natural frequency result 69 Hz with bump test result 73 Hz.
- Vibration level would be increased to 8 mm /sec (0-P) with Max, rotating speed.

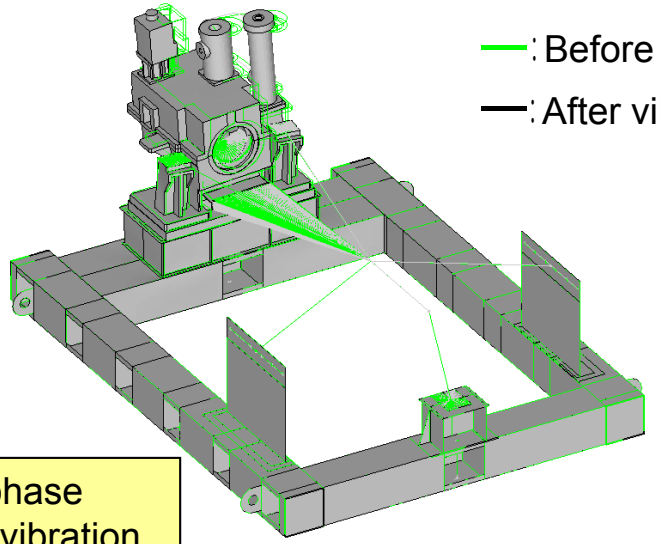


5.4 Analysis result of original pedestal in cold condition

Summary of Analysis result

Vibration mode (69.2Hz) of fabricated pedestal in final analysis

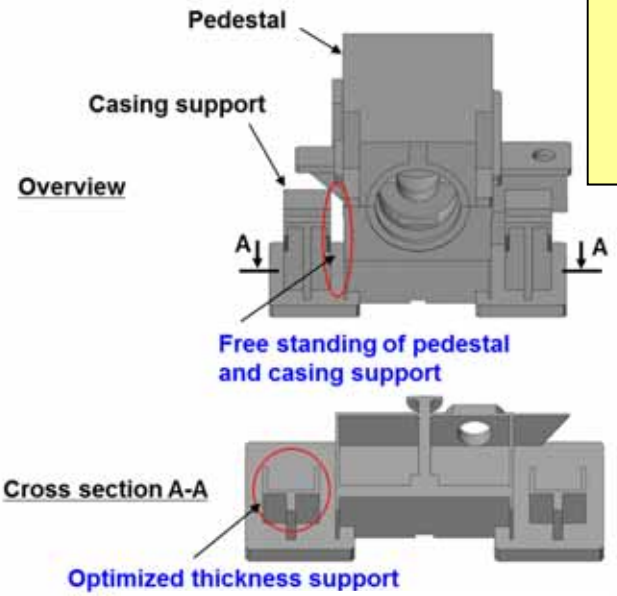




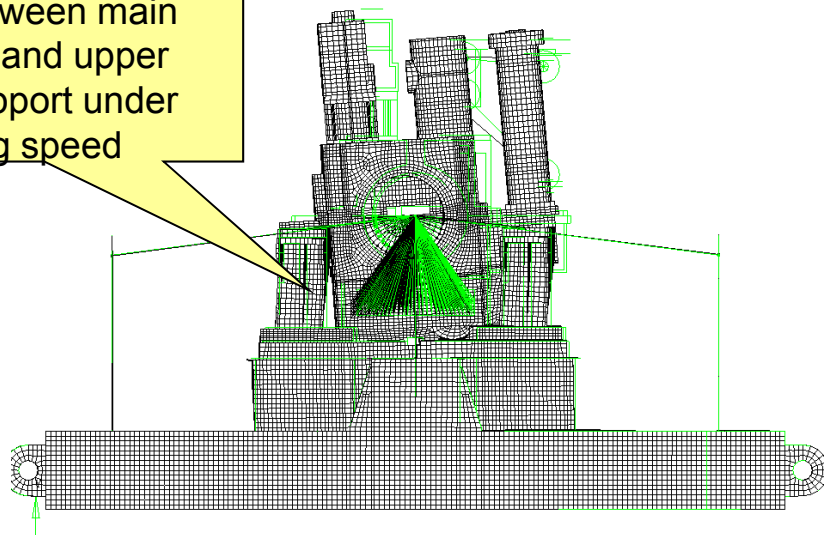
: Before vibration

: After vibration

The out-of-phase (reverse phase vibration mode) between main pedestal and upper casing support under rotating speed



Original pedestal outline



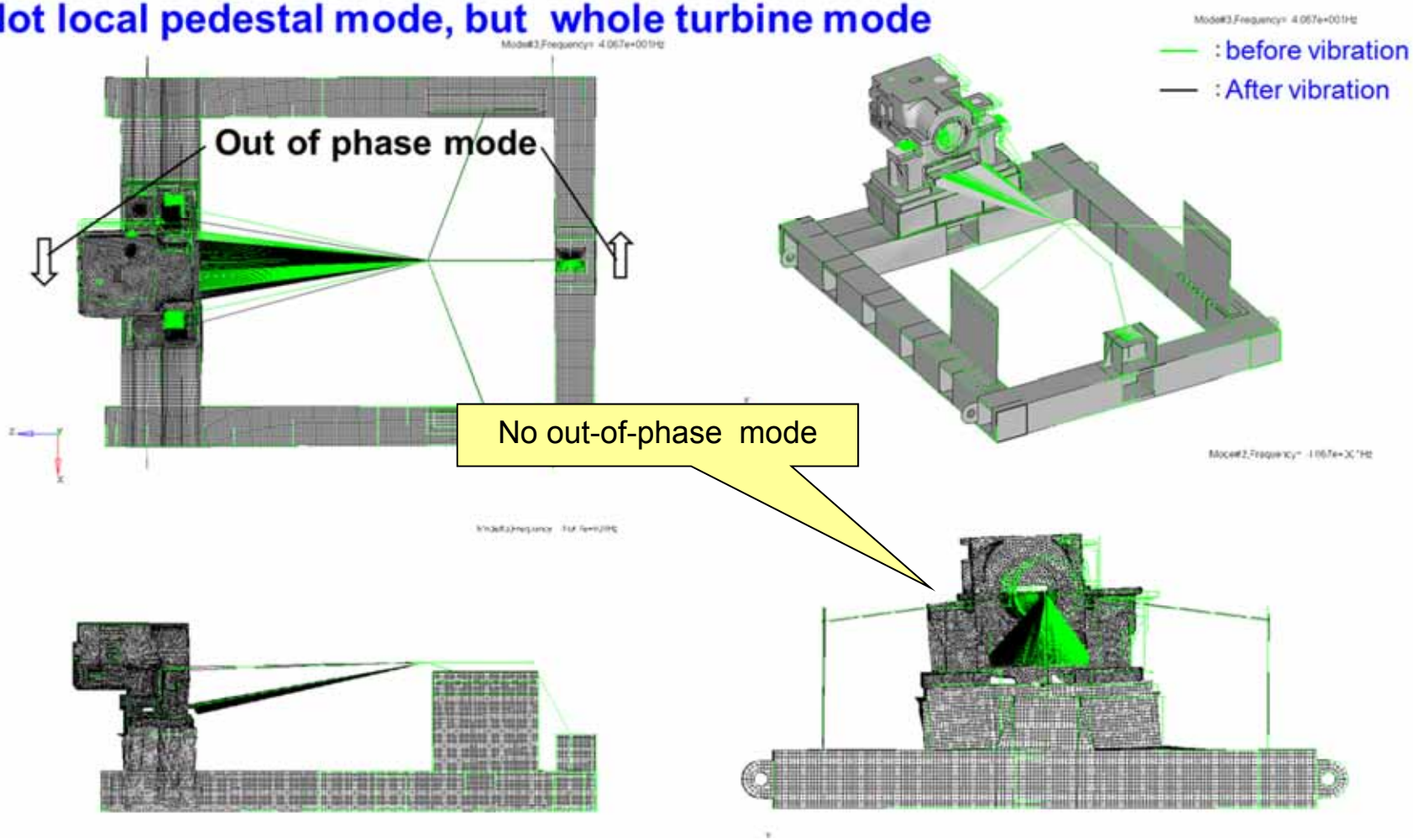
Analysis vibration mode result of current pedestal

7.3 3D analysis result of improved pedestal in hot condition

Summary of Analysis result

Vibration mode (40.7 Hz) of casting pedestal in revised final analysis

Not local pedestal mode, but whole turbine mode



Analysis vibration mode result of new pedestal